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(54) Title: METHOD FOR CLAY EXFOLIATION, COMPOSITIONS THEREFORE, AND MODIFIED RUBBER CONTAINING  
SAME

(57) Abstract: A polymer composition of low gas permeability. The composition includes an exfoliated organically-modified clay,  
butyl rubber, and a polymeric exfoliant. A method for producing the butyl composition by dry mixing the butyl rubber with the  
exfoliated clay is also provided.

**METHOD FOR CLAY EXFOLIATION, COMPOSITIONS THEREFORE, AND  
MODIFIED RUBBER CONTAINING SAME**

**BACKGROUND OF THE INVENTION**

[0001] The present invention relates to a rubber composition having low gas permeability. More particularly, the present invention relates to a clay filled butyl rubber composition having low gas permeability. Furthermore, the present invention relates to a process for the exfoliation of clay materials.

[0002] Butyl rubber is a synthetic elastomer typically comprised of a copolymer of isobutylene and isoprene. Butyl rubber was first produced with the advent of World War II and the associated limited supply of natural rubber.

[0003] Butyl rubber has a low degree of permeability to gases due to uniformity in the polyisobutylene portion of the butyl chains and the ease of packing provided by this uniformity. Butyl rubber can be 8-10 times more resistant to gas permeability than natural rubber and also has excellent resistance to heat, steam and water. The low degree of permeability to gases accounts for a frequent use of butyl rubber in inner tubes and tire inner liners. Similarly, butyl rubber is advantageously used in air cushions, pneumatic springs, air bellows, accumulator bags, and pharmaceutical closures. Furthermore, the thermal stability of butyl rubber makes it suitable for construction of tire-curing bladders, high temperature service hoses, and conveyor belts for handling hot-materials. Butyl rubber has also been used in damping mounts for engines and similar apparatus.

[0004] Notwithstanding its many desirable characteristics, in-chain unsaturation in butyl rubber, contributed by the presence of isoprene monomer units in the backbone, can be attacked by atmospheric ozone. These attacks may, over time, lead to oxidative degradation, which may subsequently lead to chain cleavage. This potential breakdown of the rubber could result in lower damping properties. One way to limit the impact of atmospheric gases on the butyl rubber structure is to further lower the gas permeability of the rubber composition.

[0005] It is known that the addition of exfoliated clays to certain types of rubber compositions may be an effective way to lower gas permeability. To lower gas permeability in rubber, the added clay must be of a small size, a condition traditionally achieved by exfoliation. Typical clays, prior to exfoliation, have a layered structure with a gap of about 0.1 nm between each layer and positively charged ions on the surface of each layer. The positively charged ions are attached by an ionic interaction with the negative surface of the clay layers, and create a net neutral charge between clay layers.

[0006] Traditional exfoliation is generally conducted as follows. Clay is first swelled by placing it in water. Swelling takes place because the positively charged ions become solubilized in the water, leaving adjacent negatively charged clay layers. The adjacent clay layers are repulsed by their similar negative charges, resulting in gaps of up to about 3 nm between the layers. An organic salt, such as cetyltrimethylammonium bromide or benzalkonium chloride is then added to the swollen clay to form an organo-clay. The organic salt is attracted to the negatively charged surface of the clay, keeping the swelling state stable and gaps of about 5-

10 nm between the layers. This organo-clay is then dried and subsequently placed in an organic solvent, such as toluene. A polymer such as polypropylene or nylon is then added to further separate the layers of the clay. Moreover, the polymer is attracted to the organic salt and therefore penetrates between clay layers. The large molecule size of the polymer serves to counteract any remaining Van der Waals interactions between the layers and the clay becomes fully exfoliated, i.e. separated into discrete layers.

[0007] Previous attempts to incorporate exfoliated clay in butyl rubber have proven largely unsuccessful due to the poor interaction of butyl rubber with the organic salts used to make the organo-clay. Therefore, it would be desirable to develop an improved method of dispersing an exfoliated clay in butyl rubber to lower gas permeability.

#### SUMMARY OF THE INVENTION

[0008] The present invention is directed to a modified clay product which can be incorporated into butyl rubber.

[0009] In accordance with the above, a first aspect of the invention is to provide a polymeric exfoliant that is an exfoliant for clay.

[00010] A further aspect of the invention is to provide a method for exfoliating clay by using the polymeric exfoliant that will exfoliate the clay.

[00011] Another aspect of the invention relates to a process for producing a randomly  $\text{NR}_2$ -functionalized poly(isobutylene) by co-polymerizing isobutylene with a vinylbenzylamine compound.

[00012] A further aspect of the invention relates to the synthesis of poly(isobutylene-co-N,N-dimethylvinylbenzylamine) by copolymerizing isobutylene and N,N dimethylvinylbenzylamine.

[00013] A further aspect of the invention relates to making polyisobutylene quaternary salt (PIBQS), polyisobutylene with multiple quaternary salts ( $\text{PIB}_2\text{QS}_2$ ), or polyisobutylene amine salt (PIBAS) by reacting polyisobutylene succinic anhydride (PIBSA) with a tertiary amine and a quaternizing agent or HCl.

[00014] A further aspect of the invention is to provide a method for lowering the gas permeability of butyl rubber by incorporating an exfoliated organo-modified clay into the butyl rubber. The polymeric exfoliant, such as PIBQS,  $\text{PIB}_2\text{QS}_2$ , PIBAS, poly(isobutylene-co-N,N-dimethylvinylbenzylamine) or modified butyl rubber can be reacted with clay and used alone without using an organo-modified clay, or advantageously used in combination with a low molecular weight surfactant used to form an organo-modified clay.

[00015] A further aspect of the invention is to provide a butyl rubber composition that has been modified with an exfoliated clay thereby imparting low gas permeability properties to the butyl rubber.

[00016] Another aspect of the invention is to provide a butyl rubber composition having low gas permeability wherein an exfoliant selected from poly(isobutylene-co-N,N-dimethylvinylbenzylamine), polyisobutylene quaternary ammonium salt (PIBQS), polyisobutylene amine salt (PIBAS), polyisobutylene with multiple quaternary salts, (PIB<sub>2</sub>QS<sub>2</sub>)<sub>r</sub> modified butyl rubber is admixed with an organo-modified clay and butyl rubber.

[00017] A further aspect of the invention is to provide a method for making an organo-modified clay product which can be exfoliated into butyl rubber by dry mixing.

[00018] These and other aspects and advantages of the present invention will become apparent upon reading the detailed description below.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[00019] The invention may take form in various components and arrangements of components, and in various steps and arrangements of steps. The drawings, in which like reference numerals denote like components throughout the several views, are only for purposes of illustrating preferred embodiments and are not to be construed as limiting the invention.

[00020] FIG. 1 shows small angle x-ray scattering (SAXS) of poly(isobutylene-co-N,N-dimethylvinylbenzylamine) exfoliated clay in butyl rubber.

[00021] FIG. 2 shows small angle x-ray scattering (SAXS) of PIBQS exfoliated clay in butyl rubber.

[00022] FIG. 3 shows small angle x-ray scattering (SAXS) of PIBQS exfoliated clay which has been dry mixed in butyl rubber.

[00023] FIG. 4 shows small angle x-ray scattering (SAXS) for PIBQS exfoliated clay with and without low molecular weight surfactant contributions as dry mixed in butyl rubber.

[00024] FIG. 5 shows comparative small angle x-ray scattering (SAXS) for  $\text{PIB}_2\text{QS}_2$  exfoliated clay with and without low molecular weight surfactant contributions as dry mixed in butyl rubber.

[00025] FIG. 6 shows comparative small angle x-ray scattering (SAXS) for PIBQS exfoliated clay with and without low molecular weight surfactant contributions as dry mixed in butyl rubber.

[00026] FIG. 7 shows comparative small angle x-ray scattering (SAXS) for  $\text{PIB}_2\text{QS}_2$  exfoliated clay with and without low molecular weight surfactant contributions as dry mixed in butyl rubber.

#### DETAILED DESCRIPTION OF ILLUSTRATIVE EMBODIMENTS

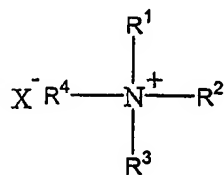
[00027] The present invention provides a butyl rubber composition with low gas permeability. The low gas permeability of the composition is achieved by

dispersing an exfoliated clay in a butyl rubber composition. The inclusion of an exfoliated clay in the butyl rubber helps to reduce the gas permeability, thereby increasing and prolonging the damping properties of the butyl rubber composition.

[00028] A variety of clays may be implemented in the present invention, provided the clay is capable of being exfoliated. Exemplary clays include, but are not limited to, pyrophyllite, smectites, illites, glauconites, vermiculites, polygorskines, sepiolites, allophanes, imogolites, synthetic mica, and mixtures thereof. Preferred clays are smectites, and the most preferred smectites are montmorillonite (Bentonite), beidellite, nontronite, hectorite, saponite, sauconite, and mixtures thereof.

[00029] The initial step in the clay exfoliation may include treating the clay with one or more low molecular weight organic surfactants to obtain an organically modified clay. More particularly, an ionic organic surfactant having a molecular weight of less than about 2000, preferably less than about 500 is used to form an organo-modified clay.

Exemplary materials include organic salts which may have the general structure:





wherein X is a halide and R<sup>1</sup>, R<sup>2</sup>, R<sup>3</sup>, and R<sup>4</sup> are selected from H and C<sub>1</sub>-C<sub>30</sub> alkyl chains, which may be linear or branched, further wherein the alkyl chain may optionally contain an aromatic moiety. At least one of R<sup>1</sup>-R<sup>4</sup> should be a C<sub>4</sub>-C<sub>30</sub> alkyl chain as described previously.

Preferred ionic organic surfactant materials include organic ammonium salts, such as dimethyldioctadecyl ammonium. Other organic salts include, but are not limited to, cetyltrimethylammonium bromide, and benzalkonium chloride, and mixtures thereof. Alternatively, a polar polymeric material such as a polyether may be employed.

[00030] An exfoliation polymer can then be added to the solution containing the organically modified clay. The exfoliation polymer according to the present invention is one which will exfoliate into organically modified clay and preferably compatibilize the clay with butyl rubber. The exfoliated clay, when combined with the butyl rubber, provides a butyl rubber which has low gas permeability.

[00031] In accordance with the invention, polymeric compounds have been developed which, when incorporated into a clay product, possess the desired property of being able to exfoliate the clay into butyl rubber to lower the gas permeability of the butyl rubber.

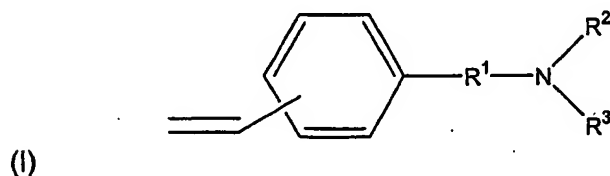
[00032] According to one embodiment of the invention, the exfoliation polymer is a modified butyl rubber. Preferred butyl rubber compositions include (i) alkene monomers such as ethylene, propylene, butylenes, isobutylene, pentene, hexene, heptene, etc., as well as any di- or tri-alkene, or mixtures thereof, and (ii) multiolefin monomers, such as isoprene, p-methylstyrene or mixtures thereof. The butyl rubber is typically composed of approximately 70-99.5 mol percent of alkene units and approximately 30-0.5 mol percent of multiolefin units, and preferably approximately 90-99.5 mol percent of alkene units and 10-0.5 mol percent multiolefin units.

[00033] The term "multiolefin", as used herein, includes olefins of 4-16 carbon atoms, such as butadiene, cyclopentadiene, piperylene, isoprene, and 1,3-dimethylbutadiene, isoprene; 2,3-dimethyl-butadiene-1,3; 1,2-dimethyl-butadiene-1,3 (3-methyl pentadiene-1,3); 1,3-dimethyl butadiene-1,3; 1-ethyl butadiene-1,3 (hexadiene-1,3); 1,4-dimethyl butadiene-1,3 (hexadiene-2,4); and methylstyrene.

[00034] These butyl rubbers can be prepared according to any polymerization process known in the art but are also "modified" by bromination, wherein a reactive benzylic bromine functionality is formed selectively on the vinyl aromatic monomers. Particularly preferred modified butyl rubbers include poly(ethylene-co-propylene-co-bromo-*p*-methylstyrene), available as Exxpro™.

[00035] One further exemplary compound which has the desired properties of exfoliating clay into butyl rubber to lower the gas permeability of the butyl rubber is a randomly NR<sub>2</sub>-functionalized poly(isobutylene). A process for

preparing the randomly NR<sub>2</sub>-functionalized poly(isobutylene) involves:  
 copolymerizing isobutylene and a compound having the formula (I):



where R<sup>1</sup> is a bond or is an alkylene group selected from C<sub>1</sub>-C<sub>18</sub> linear or branched alkylene, C<sub>3</sub>-C<sub>20</sub> cycloalkylene and C<sub>6</sub>-C<sub>24</sub> arylene groups where R<sup>1</sup> may contain ether or tertiary amine groups. The R<sup>2</sup> and R<sup>3</sup> groups are independently selected from C<sub>1</sub>-C<sub>18</sub> linear or branched alkyl, C<sub>3</sub>-C<sub>20</sub> cycloalkyl and C<sub>6</sub>-C<sub>24</sub> aromatic where the R<sup>2</sup> and R<sup>3</sup> groups may contain ether or tertiary amine groups.

[00036] The substituents on the vinyl aromatic group may be attached in any of the meta, ortho, or para positions. In these styryl derivatives, the para position is preferred. The R<sup>1</sup> group forms a linkage between the vinyl aromatic hydrocarbon and the amine group, however if R<sup>1</sup> is an ether, the part of the R<sup>1</sup> group attached to amine should be alkylene. Alternatively, the amine may be attached directly to the vinyl aromatic hydrocarbon. Of course, the invention also includes naphthalene and other vinyl aromatic monomers wherein the R<sup>1</sup>NR<sup>2</sup>R<sup>3</sup> substituent can be attached at any ring position. Typically the compound of formula (I) is an N,N-dialkylaminoalkylenyl substituted styrene.

[00037] The co-polymerization of the isobutylene and the compound of formula (I) takes place in a solvent system in the presence of a Lewis acid or Bronsted acid. The polymerization reaction can be initiated by a carbenium ion. Typical methods for generating suitable carbenium ions are by reaction of alkyl halides with Lewis acids or reaction of Bronsted acids with an alkene. In the Lewis acid system, the polymerization is initiated by the presence of an alkyl halide and a Lewis acid, the former may be referred to herein as an initiator and the latter as a co-initiator. Accordingly, the Lewis acid and alkyl halide may be first combined and added to the vinyl aromatic and tertiary alkene monomers and or added thereto separately in any order. The preferred method is to add the alkyl halide to the monomers and then add the Lewis acid. Multifunctional initiators may be synthesized using polyhalogenated species and a Lewis acid. Preferred initiator systems include Lewis acids, such as  $\text{TiCl}_4$ ,  $\text{BCl}_3$ ,  $\text{AlCl}_3$ ,  $\text{Et}_2\text{AlCl}$ ,  $\text{EtAlCl}_2$ , and mixtures thereof, and an alkyl halide from the list  $\alpha$ ,  $\alpha$ ,  $\alpha'$ ,  $\alpha'$  tetramethyl-1,4-benzene dimethyl chloride, t-butyl chloride, t-butyl bromide, 2-chloro-2-phenylpropane, 2-bromo-2-phenylpropane, 2-chloro-2-methylpentane, 2-bromo-2-methylpentane, 2-chloro-2-methylbutane, 2-bromo-2-methylbutane, 1,3-(2-chloro-2-propyl)-5-t-butyl benzene and 1,3-(2-bromo-2-propyl)-5-t-butyl benzene, and mixtures thereof. A preferred initiator system is  $\alpha$ ,  $\alpha$ ,  $\alpha'$ ,  $\alpha'$  tetramethyl-1,4-benzene dimethyl chloride and titanium tetrachloride.

[00038] It is known that Lewis acids, particularly  $\text{TiCl}_4$ , will react with nitrogen containing species. Accordingly, since a tertiary amine group is a required constituent of the copolymerized vinyl aromatic monomers, one skilled in the art

may expect this to deactivate Lewis acid catalysts. Surprisingly, this does not occur in the present polymerization. As a result,  $\text{TiCl}_4$  co-initiation of the copolymerization of tertiary alkene monomers and tertiary amine substituted vinyl aromatic hydrocarbons provides an efficient, one-step polymerization process.

[00039] The polymerization is preferably carried out at low temperatures, such as below about  $0^\circ\text{C}$ , more preferably below about  $-20^\circ\text{C}$ , and most preferably below about  $-50^\circ\text{C}$ , under an inert atmosphere, such as  $\text{N}_2$  or Ar. The initiator is added to a charge of substituted vinyl aromatic hydrocarbon monomer and tertiary alkene monomer in a polymerization vessel and living polymerization is initiated by addition of the co-initiator. The alkyl halide is added in an amount of about 0.001 to 0.1 mol per 100 grams monomer, more preferably between about 0.004 and 0.1 mol per 100 grams monomer, most preferably between about 0.004 and 0.02 mol per 100 grams monomer. The polymerization is allowed to continue until substantially 100% of monomer conversion is completed. The polymerization can be terminated by the addition of a terminator, such as an alcohol, although other terminators known in the art would also be suitable. The resulting polymers are tertiary amine modified polyisobutylene. The polymer compositions thus formed may be telechelic and/or may include random polymerization of the tertiary alkene and vinyl aromatic hydrocarbon monomer units.

[00040] The polymer preferably has a  $M_n$  range of about 1000 to about 100,000, more preferably between about 1000 and 25,000 as measured by gel

permeation chromatography (GPC) using universal calibration and the following Mark-Houwink constants for polyisobutylene:  $K=0.000085$ ,  $\alpha=0.75$ . Tertiary alkene monomer contributed units preferably comprise between about 46.6 and 99.5 wt% of the total polymer composition, more preferably between about 89.3 and 97.9 wt% of the total polymer composition, while the substituted vinyl aromatic contributed units comprise between about 54.4 and 0.5 wt% of the total polymer composition, more preferably between about 10.7 and 2.1 wt%.

[00041] In a more specific embodiment, a process for synthesizing a randomly  $\text{NR}_2$ -functionalized poly(isobutylene) by cationic polymerization comprises the steps of:

- a) mixing isobutylene in a solvent system;
- b) cooling the isobutylene/solvent mixture;
- c) adding N,N-dimethylvinylbenzylamine to the mixture along with an initiator and modifiers;
- d) initiating a polymerization reaction by adding  $\text{TiCl}_4$ ;
- e) terminating the polymerization with MeOH; and
- f) evaporating any remaining solvents;

wherein the resulting product of poly(isobutylene-co-N,N-dimethylvinylbenzylamine) is yielded.

[00042] The solvent system may comprise solvents, such as hydrocarbon solvents, including hexane and heptane, aromatic solvents including toluene and xylene, chlorinated solvents including methylchloride, methylene chloride, chloroform, and mixtures of these. In one embodiment, the solvent system comprises hexane and methyl chloride.

[00043] In an alternative embodiment, the exfoliation polymer comprises surfactant includes, for example, PIBQS, PIBAS,  $\text{PIB}_2\text{QS}_2$ , and poly(isobutylene-co-N,N-dimethylvinylbenzylamine). The exfoliation polymeric surfactant can be dissolved in a solvent such as, for example, THF, diethyl ether, toluene, isopropanol, acetone, methyl ethyl ketone (MEK), and any other solvent(s) that will dissolve the exfoliation polymer and would not interfere with the intercalation ability of the polymer. Alcohol can also be added to the polymer THF mixture.

[00044] A process for preparing PIBQS,  $\text{PIB}_2\text{QS}_2$  and PIBAS involves reacting polyisobutylene succinic anhydride (PIBSA) with a tertiary amine to produce polyisobutylene succinimide which is then reacted with HCl to form the PIBAS or an alkylating agent to form PIBQS/  $\text{PIB}_2\text{QS}_2$ . Suitable alkylating agents to form quat salts include, but are not limited to, methyl chloride, benzyl chloride, dimethyl sulfate, diethylsulfate, and  $\alpha,\alpha'$ -dibromo-xylene. A review of quaternary ammonium compounds can be found in the Encyclopedia of Chemical Technology, 4<sup>th</sup> edition, (1996), John Wiley and Sons.

[00045] In particular, the process for preparing the PIBQS comprises:

- a) mixing polyisobutylene succinic anhydride (PIBSA) with a multi- amine compound selected from, for example, 3-(dimethylamino)propylamine, tetraethylene pentamine, 3,3'-diamino-N-methyl dipropylamine, 1-(2-aminoethyl)piperazine, 4-amino-1-benzylpiperidine, dimethylaminovinylbenzylamine, polyethyleneimine, 3-aminopyrrolidine, 3-(dimethylamino)pyrrolidine and N,N'-Bis(3-aminopropyl)ethylene diamine;
- b) heating the mixture to about 150°C;
- c) maintaining the heated mixture at about 150°C for about five minutes;
- d) allowing the mixture to cool;
- e) adding HCl and water to the cooled mixture of step d);

wherein PIBAS is thereby formed.

[00046] By first dissolving the polymeric surfactant into a solvent, i.e., the polymeric surfactant dissolved into THF diethyl ether, MEK or other solvents which would dissolve the polymeric surfactant and would not interfere with the intercalation ability of the polymer, and then subsequently adding this to the swelled clay, the ion exchange reaction necessary for the polymer surfactant to diffuse into the swelled clay sheets becomes possible. Using this alternative



procedure, it is possible for the polymer surfactant to diffuse into and intercalate the clay.

[00047] The organo-modified clay provided in accordance with the alternative embodiment can be advantageously exfoliated into butyl rubber by a dry mixing method under mild mixing conditions compared to conventional exfoliation processes. Such mild mixing conditions are, for example, similar to those normally used in butyl rubber mixing. The mixing conditions may be accomplished, for example, by using any integral mixing devices such as a Brabender mixer, a twinscrew extruder or a kneader, at a mixing rate of from about 1 to about 500 rpm and a temperature of about 25°C to about 300°C for a period of up to about ten minutes. Typical butyl rubber mixing conditions are, for example, using a Brabender mixer at about 30 to about 120 rpm, at about 70°C to about 175°C for about two to about ten minutes. In one embodiment the butyl rubber mixing conditions are for example, mixing at about 60 rpm at a temperature of about 70°C for about three minutes. Preferably, the clay is at least about 85% exfoliated, more preferably at least about 90% exfoliated. The exfoliated clay preferably has a plate size between about 0.1 and about 100  $\mu\text{m}$ .

[00048] The organically-modified swollen clay, organic solvent, and polymeric surfactant are preferably combined to yield a solution containing between about 40 and about 95 wt.% solvent, more preferably between about 70 and about 90 wt.%; between about 5 and about 25 wt.% polymer, more preferably between about 8 and about 20 wt.%; and between about 0.01 and about 8 wt.%

clay, more preferably between about 0.25 and about 6 wt.%. Preferably, the clay/organic solvent/polymer solution will include at least about 5% clay particles.

[00049] Gas permeability has been improved by using the clay treated with the combination of the exfoliation polymer and the low molecular weight surfactant. However, it can be difficult for the exfoliation polymer to be dissolved into aqueous solution. Alternatively, it can be difficult for the low molecular weight surfactant to be dissolved into organic solvent. Furthermore, water is advantageously used in clay swelling and for an ion exchange reaction. Accordingly, a preferred method for carrying out the invention includes first dissolving the exfoliation polymer into THF and separately forming a mixture of clay and low molecular weight surfactant. The exfoliation polymer solution is then added to the mixture of the clay and the low molecular weight surfactant. After that, alcohol and water are added to the solution. This procedure provides the exfoliation polymer and the low molecular weight surfactant with improved mechanisms to diffuse into and intercalate the clay. As the result, it is believed that the exfoliation polymer and the low molecular weight surfactant exchanges the sodium ion of the clay.

[00050] After the exfoliation step has been completed, the clay/organic solvent/polymer solution (now an exfoliated clay) can be dried to yield an exfoliated clay/polymer composition and added to a butyl rubber composition. It is also contemplated that the clay/polymer composition be separated from the organic solvent, e.g., by filtration or evaporation. Of course, it is also envisioned that the exfoliated clay can be added in the form of the solution comprised of a polymeric

surfactant organically modified clay and solvent. As used herein, the butyl rubber composition is intended to include isobutylene, halobutyl rubber, and copolymers of isobutylene and one or more additional monomers, such as isoprene, styrene, butadiene, and mixtures thereof.

[00051] The exfoliated clay/polymer composition is typically added to the butyl rubber at elevated temperatures, such as between about 50°C to about 175°C, preferably between about 70°C and about 150°C, more preferably between about 80°C and about 140°C. The addition can be carried out as a dry mixing process in any conventional mixer, such a Brabender mixer, which is preferably purged with an inert gas such as N<sub>2</sub> prior to charging the components. The addition of the clay/polymer composition may be also carried out at a pressure from slightly above vacuum to about 2100 kPa, under substantially dry conditions. Of course, the butyl rubber can be added according to any method known by the skilled artisan.

[00052] In any event, it is preferred that between about 1 and about 99% by weight clay/polymer composition is incorporated in the butyl rubber composition. More preferably, between about 3 and about 70%. Most preferably, it is desirable that a suitable amount of clay/polymer composition be dispersed in the butyl rubber composition to achieve an air permeability less than about 100 mL/m<sup>2</sup> day, more preferably less than about 80 mL/m<sup>2</sup> day. Because butyl rubber compositions can vary with respect to starting air permeability, the addition of the clay/polymer composition preferably achieves an at least about 20% reduction in air permeability, more preferably, at least about 50%.

[00053] It is frequently desirable to include other additives known in the art to the compositions of the present invention. Suitable additives include stabilizers, antioxidants, conventional fillers, processing aids, accelerators, extenders, curing agents, reinforcing agents, reinforcing resins, pigments, fragrances, and the like. Other additives known in the art are also contemplated for use in the present invention. Specific examples of useful antioxidants and stabilizers include 2-(2'-hydroxy-5'-methylphenyl) benzotriazole, nickel di-butyl-di-thiocarbamate, tris(nonylphenyl) phosphite, 2,6-di-*t*-butyl-4-methylphenol, and the like. Exemplary conventional fillers and pigments include silica, carbon black, titanium dioxide, iron oxide, and the like. Suitable reinforcing materials are inorganic or organic products of high molecular weight. Examples include glass fibers, asbestos, boron fibers, carbon and graphite fibers, whiskers, quartz and silica fibers, ceramic fibers, metal fibers, natural organic fibers, and synthetic organic fibers. These compounding ingredients are incorporated in suitable amounts depending upon the contemplated use of the product, preferably in the range of about 1-350 parts of additives or compounding ingredients per 100 parts of the butyl rubber composition.

[00054] The butyl rubber composition of the present invention is useful in the formation of inner liners for automobile tires and in applications requiring good damping characteristics, such as engine mounts. Other uses for the butyl rubber compositions of the invention include use in air cushions, pneumatic springs, air bellows, accumulator bags, tire-curing bladders, high temperature service hoses, and conveyor belts for handling hot materials.

[00055] In the following, the present invention will be described in more detail with reference to non-limiting examples. The following examples and tables are presented for purposes of illustration only and are not to be construed in a limiting sense.

## EXAMPLES

### Synthesis of Initiator

[00056] 400 mL of  $\text{CH}_2\text{Cl}_2$  and 41.68g (0.215 mol)  $\alpha,\alpha,\alpha',\alpha'$ -tetramethyl-1,4-benzene dimethanol (99%, Aldrich) were added to a nitrogen purged, 3-necked 1000 mL round bottom flask equipped with a reflux condensor with stirring. To this solution was slowly added 31.3 mL (0.215 mol) of thionyl chloride (99+%, Aldrich) over 15 minutes. After 12 hours, the solution was rotary evaporated yielding white crystals of  $\alpha,\alpha,\alpha',\alpha'$ -tetramethyl-1,4-benzene dimethylchloride. The product was recrystallized twice from hexane and stored at  $-20^\circ\text{C}$  until used. Directly prior to use, the crystals were recrystallized once more from hexane to obtain  $\alpha,\alpha,\alpha',\alpha'$ -tetramethyl-1,4-benzene dimethylchloride: mp= $69-70^\circ\text{C}$ ,  $^1\text{H-NMR}(\text{CDCl}_3)$ : 7.56 ppm, 4H, s; 1.99 ppm, 12H, s.

### EXAMPLE 1 Synthesis of Poly(isobutylene-co-N,N-dimethylvinylbenzylamine)

[00057] To a 1L  $\text{N}_2$  purged bottle was added 173.2g of 23 wt.% isobutylene in hexane and 272.6g of methyl chloride with stirring. The bottle was cooled to  $-78^\circ\text{C}$  and 1.5 mL dimethylacetamide (Aldrich), 0.8 mL di-*t*-butylpyridine (Aldrich), 1.98 g of  $\alpha,\alpha,\alpha',\alpha'$ -tetramethyl-1,4-benzene dimethylchloride (prepared

according to the synthesis set forth above) and 1.38g of N,N-dimethylvinylbenzylamine (Aldrich) were added. Upon addition of 4 mL of  $\text{TiCl}_4$  (Aldrich) the polymerization was initiated and the temperature rose to  $-60.7^\circ\text{C}$ . After 43 minutes, an additional 2 mL of  $\text{TiCl}_4$  was added. After 90 minutes, the reaction was terminated with 20 mL methanol. The methyl chloride was evaporated and the resulting hexane solution extracted with 300 mL methanol. Evaporation of the solvent yielded poly(isobutylene-co-N,N-dimethylvinylbenzylamine) with the following properties:  $M_n = 9.4 \times 10^3$  g/mol,  $M_w = 1.34 \times 10^4$  g/mol. Integration of the N-( $\text{CH}_3$ )<sub>2</sub> peaks in the  $^1\text{H}$ -NMR spectrum and comparison to the polyisobutylene methyl group revealed 1.67 N,N-dimethylvinylbenzylamine incorporated per chain.

#### EXAMPLE 2 Organo-Montmorillonite

The layered silicate was a montmorillonite (a natural Bentonite clay from Southern Clay Products, Gonzales, TX) with a charge exchange capacity (CEC) of about 98 mequiv/100g. The clay was organically modified with benzalkonium chloride (Aldrich, Milwaukee, WI) through a cation exchange reaction. In this reaction, 200 mL of a benzalkonium chloride/water solution (30 wt.%) was used to treat 50 g of the clay. The reaction was performed in a sealed flask and the reactants were shaken for 20 hrs at  $23^\circ\text{C}$ . The mixture was then filtered through a filter paper. Thereafter, the clay was dispersed in another 200 mL of the benzalkonium chloride/water solution. The process was repeated three times. Finally, excess

benzalkonium chloride was removed using isopropanol to wash the product. After vacuum drying, the modified montmorillonite contained about 45% organo-matter (i.e., benzalkonium), as measured by thermo-gravity analysis (TGA). TGA was carried out on equipment manufactured by TA Instruments and Perkin Elmer, among others.

#### EXAMPLES 3-5 Clay Particle Exfoliation

[00058] The required amounts (from Table 1 below) of toluene, butyl rubber (MH-11), treated silicate (example 2), and a 10 wt.% solution of poly(isobutylene-co-N,N-dimethylvinylbenzylamine) (Example 1) in toluene were charged into a 950 mL bottle. The bottle was then placed on a mechanical shaker for 24 hours, and the polymer and treated silicate were dissolved in toluene. Excess surfactant was then extracted with EtOH and the resulting material was then drum dried. Small angle x-ray scattering (SAXS) shows that addition of poly(isobutylene-co-N,N-dimethylvinylbenzylamine) improves the exfoliation of the clay into the butyl rubber (FIG. 1). Particularly, in example 5, where no montmorillonite lamellar peak was observed, indicating that the clay is completely exfoliated.

[00059] Table 1

		Example 3	Example 4	Example 5
Toluene	ml	300	255ml	180ml
MH-11	(g)	40	40	40
Treated silicate	(g)	4	4	4
2562-71-1*		0	45ml	120ml

\*2562-71-1 is a 10 wt.% solution of poly(isobutylene-co-N,N-dimethylvinylbenzylamine) in toluene

[00060] The following table shows the effects of the poly(isobutylene-co-N,N-dimethylvinylbenzylamine) treated clay on gas permeability of butyl rubber.

Table 2

Pure Butyl Rubber (GPI-gas permeability index)**	Butyl Rubber + organo-clay + 2562-71-1 (GPI-gas permeability index)
1	0.294
1	0.384
1	0.304
1	0.457
1	0.353 (Avg)

\*2562-71-1 is a 10 wt.% solution of poly(isobutylene-co-N,N-dimethylvinylbenzylamine) in toluene

\*\* GPI (gas permeability index) is calculated according to the formula:  $GPI = \frac{P_c}{P_p}$  where  $P_c$  = permeability of the nanocomposite and  $P_p$  = the permeability of the polymer.

[00061] As can be seen from Table 2, the additional of the poly(isobutylene-co-N,N-dimethylvinylbenzylamine) treated clay to butyl rubber lowers the gas permeability of the butyl rubber.

#### EXAMPLE 6 Synthesis of PIBAS

[00062] The synthesis starts with polyisobutylene succinic anhydride (PIBSA). PIBSA has been obtained from the Chevron Chemical Company and is made by a thermal process. The PIBSA used is ORONITE® OL15500 with a Mn ~ 1,000 and Mw ~ 1,900. PIBSA is a viscous liquid.

[00063] 200.9g. of PIBSA was weighed into a beaker. 25 ml of 3-(dimethylamino)propylamine [M.W. = 102.18g/m, d=0.812] was added and mixed



in. An exotherm occurred. The mixture was heated to 150°C, maintained at 150°C for 5 minutes and then allowed to cool. The resulting material is a medium viscosity oil. This material is designated polyisobutylene succinimide amine (PIBSIA). 40ml. of 5.2M HCl in H<sub>2</sub>O was added and mixed in. The solution was then thickened to a paste. This is PIBAS with occluded water. PIBAS is an acronym for the polyisobutylene amine salt. The amine salt of dimethylaminopropylamine amine may also be present.

#### EXAMPLES 6A Synthesis of PIBQS

[00064] 300g of PIBSA was weighed into a beaker. 15.9 g of dimethylaminopropylamine was added to the PIBSA. The mixture was heated in a boiling water bath for about one hour. 161.4g of this product was thoroughly mixed with 13.5g of  $\alpha,\alpha'$ -dibromoxylene in a beaker and heated in a 90°C oven for sixteen hours. The product was a PIBQS.

#### EXAMPLES 7 – 13 Clay Exfoliation

[00065] Three one-liter bottles were used for the preparations. The amounts and the components are listed in Table 3 below. Toluene, butyl rubber (MH-11) the treated silicate (Example 2), and the PIBAS (Example 6) were charged into the bottle. The bottle was then placed on a mechanical shaker. After about 24 hours, the polymer and the treated silicate were dissolved into the toluene solvent. The solution was then poured into EtOH solvent to extract excess surfactant. The precipitated stock was then drum-dried. The products were checked by using the small angle x-ray scattering (SAXS). The x-ray scattering results showed that

adding PIBAS largely improves the exfoliation of the clay into the butyl rubber (FIG. 2). Using a suitable amount of PIBAS, the montmorillonite lamellar x-ray scattering peak in the stock can be shifted to low angle and eventually disappears, which indicates that the clay is finally exfoliated. However, the concentration of PIBAS plays an important role. As can be seen from the scattering chart, if one adds too much PIBAS, another peak at the low angle appears.

Table 3

	Ex 7	Ex 8	Ex 9	Ex 10	Ex 11	Ex 12	Ex 13
Toluene ml	300	→	→	→	→	→	→
MH-11 (g)	40	→	→	→	→	→	→
Treated silicate (g)	4	→	→	→	→	→	→
PIBAS	0	2	4	6	8	10	12

[00066]

Table 4 shows the effects of PIBAS treated clay on gas permeability of butyl rubber:

Table 4

Pure Butyl Rubber (GPI - gas permeability index)	Butyl Rubber + organo-clay + end/F PIBAS (GPI - gas permeability index)
1	0.401
1	0.530
1	0.328
1	0.408
1	0.415 (Avg)

[00067]

As can be seen from Table 4, the addition of PIBAS treated clay to the butyl rubber lowers the gas permeability of the butyl rubber.

[00068] The following examples illustrate the dry mixing exfoliation technique according to the present invention:

**EXAMPLE 14 Organo Treated Clay**

[00069] To a 45g portion of the PIBAS polymer surfactant produced according to Example 6 was added 100ml THF and 30 ml alcohol. This mixture was then shaken for 30 minutes at room temperature until the polymer surfactant was dissolved. Separately, 15g of montmorillonite-clay (Cloisite Na from Southern Clay Products, Gonzales, Texas) was mixed with 15ml water. The clay water mixture was allowed to sit at room temperature for about one hour to swell the clay. The swelled clay and the polymer surfactant compositions were then combined and shaken for about twenty -four hours. To give the final product, the clay was then filtered and dried.

**EXAMPLE 15 Exfoliated Clay/Butyl Rubber via Dry Mixing**

[00070] A 40g sample of butyl rubber was mixed with 16g of the organo-clay of Example 13 in a 60g-Brabender mixer at 70°C at 60rpm for three minutes. Using x-ray scattering, the clay in the rubber compound was determined to be completely exfoliated (see FIG. 3).

[00071] The following results in Table 5 show the effect on gas permeability of butyl rubber using PIBAS treated clay produced in accordance with the process described in Example 14.

[00072] Permeability Results of Rubber Compounds Containing PIBAS

## Treated Clay

Table 5

	15A	15B	15C	15D
Butyl Rubber	40	40	35	40
PIBAS Treated Clay <sup>1</sup>	4	16	23	0
Pure Clay (%)	3%	10%	14%	0%
Permeability (GPI)				
Test 1	1.042	0.672	0.596	1
Test 2	0.899	0.616	0.534	1
Test 3	0.931	0.659	0.571	1
Test 4	0.858	0.650	0.600	1
Average	0.926	0.648	0.576	1

<sup>1</sup> PIBAS Clay contains 65% PIBQS, as measured by TGA. The data was measured using a MOCON instrument (Mocon, Inc., Minneapolis, Minnesota).

[00073] As can be seen from the above test results, rubber compositions containing the newly synthesized PIBAS treated clay (15A-15C) have reduced gas permeability compared to compositions without the treated clay (15D).

**EXAMPLE 16** Organic-Montmorillonite

The layered silicate was a montmorillonite (a natural Bentonite clay from Southern Clay Products, Gonzales, TX) with a charge exchange capacity (CEC) of about 98 mequiv/100g. The clay was organically modified with benzalkonium chloride (Aldrich, Milwaukee, WI) through a cation exchange reaction. In this reaction, 200 mL of a benzalkonium chloride/water solution (30wt%) was used to treat 50 g the clay. The reaction was performed in a sealed flask and the reactants were shaken for 20 hrs at 23°C. The mixture was then filtered through a filter paper. Thereafter, the clay was disposed in another 200 mL of the benzalkonium chloride/water solution. The process was repeated three times. Finally, excess

benzalkonium chloride was removed using isopropanol to wash the product. After vacuum drying, the modified montmorillonite contained about 45% organo-matter (i.e., benzalkonium), as measured by thermo-gravity analysis (TGA). TGA was carried out on equipment manufactured by TA Instruments and Perkin Elmer, among others.

#### EXAMPLES 17 -19 Clay Particle Exfoliation

Three 4L bottles were used for the preparations. The amounts and the components for each example are listed in the Table 6 below. Toluene (Aldrich, Milwaukee, WI), Exxpro™ (Exxon, Houston, TX) rubber and the organically modified clay from Example 16 were charged into the bottle. The bottle was then placed on a bottle roller at about 30 rpm. After about 48 hrs, the rubber and the treated clay were dissolved in the toluene solvent. The solution was then drum-dried, and the resultant products analyzed via small angle x-ray scattering (SAXS) and transmission electron microscopy (TEM). The x-ray scattering showed no montmorillonite lamellar peak in the materials (i.e. full exfoliation had occurred). A TEM picture showed a montmorillonite plate of about 1,000 nm and an aspect ratio of about 1,000.

Table 6

	Example 17	Example 18	Example 19
Toluene (g)	2300	2300	2300
Exxpro 96-4 (g)	350	350	350
Treated clay (g)	35	70	105

#### EXAMPLES 20-30 Rubber Compounding

Eleven kinds of rubber compositions were prepared according to the formulations shown in Tables 7 and 8 by selectively using the exfoliated clay from Examples 17-19 in compound formulations. In each example, a blend of the ingredients was kneaded by the method listed in Table 9. The final stock was sheeted and molded at 160°C for 25 minutes. In Examples 20-30, measurement of tensile strength is based on conditions of ASTM-D 412 at 22°C. Test specimen geometry was measured via a ring with a width of 0.05 inches (0.127 cm) and a thickness of 0.075 inches (.191 cm). Air permeability tests were conducted on 1mm thick sheets according to ASTM Standard D1434. The physical characteristics of the compositions of Examples 20-30 are shown in Table 10.

Table 7

	Ex 20	Ex 21	Ex 22	Ex 23	Ex 24	Ex 25	Ex 26	Ex 27	Ex 28	Ex 29	Ex 30
Expro™ 96-4 (g)	100							50			
Ex 2 (g)		100									
Ex 3 (g)			100			50					
Ex 4 (g)				100			50				
Butyl Rubber (g)					100	50	50	50	95	90	85
Carbon Black (g)									5	10	15
Naphthenic Oil (g)	15	15	15	15	15	15	15	15	15	15	15

TABLE 8 Final Batch Formulation (For Examples 19 to 29, by parts)

Stearic acid	0.50
Sulfur	0.40
Zinc Oxide	0.75
(proceeding add) Rylex 3001	0.60
Altax-MBTS (accelerator)	0.80

TABLE 9 Mixing Conditions

Mixer:	300 g Brabender	Agitation Speed:	60 rpm
<u>Master Batch Stage</u>			
Initial Temperature		100°C	
0 min		charging polymers	
0.5 min		charging oil and Carbon Black	
5.0 min		drop	
<u>Final Batch Stage</u>			
Initial Temperature		75°C	
0 sec		charging master stock	
30 sec		charging curing agent and accelerators	
75 sec		drop	



TABLE 10 Physical Characteristics of Examples 20-30

	Ex 20	Ex 21	Ex 22	Ex 23	Ex 24	Ex 25	Ex 26	Ex 27	Ex 28	Ex 29	Ex 30
Expro™ 96-4 (parts)	100	100	100	100		50	50	50			
Butyl Rubber M- 18 (parts)					100	50	50	50	95	90	85
Clay (parts)	0	5	10	15	0	5	7.5	0			
Carbon Black (parts)									5	10	15
Tb (kPa)	1,247	3,204	5,016	6,470	1,957	4,217	4,162	1,275	2,425	3,934	5,981
Eb (%)	369	629	544	418	1053	782	808	577	1083	1010	958
Mooney Viscosity @ 300°C	135	248	504	716	66	207	206	86	65	82	103
Mooney Viscosity @ 50°C	41	73	127	193	33	61	66	36	36	43	48
Air Permeability mL/m <sup>2</sup> day (66°C)	166	111	99	73	170	132	177	177	164	162	199

**EXAMPLE 31** Synthesis of PIBQS

105.5g of polyisobutylene succinic anhydride and 5.12g of 3-(dimethyl amino) propylamine were mixed at room temperature, and then heated to between 95 and 100°C for 3 hours. To the mixture, 4.1ml of 12.1N HCl was added and mixed. The mixture was heated between 95 and 100°C for 3 hours. To remove water, the mixture was kept in a vacuum oven at 100°C for a day.

**EXAMPLE 32** Synthesis of PIB<sub>2</sub>QS<sub>2</sub>

400g of polyisobutylene succinic anhydride and 20.1g of 3-(dimethyl amino) propylamine. The materials were mixed at room temperature, and then heated between 95 and 100°C for one hour. To the mixture, 25.9g of  $\alpha, \alpha - p$  - dibromoxylene was added and mixed. The mixture was heated between 95 and 100°C for one hour. The mixture was kept in the vacuum oven at 100°C for 4 hours to remove water.

**EXAMPLE 33 – 50** Making the Organo-treated Clay

A small amount of the polymer exfoliant of Example 31 or 32, according to Table 11, and 6.7g THF were combined. The mixture was then shaken for 30 min at room temperature until the polymer exfoliant was dissolved.

1g of (Cloisite Na) clay and a small amount of dioctadecyldimethyl ammonium (low molecular weight surfactant) according to Table 11 were combined. To the mixture of the clay and the low molecular weight surfactant, the mixture of polymer exfoliant was added, and then shaken for a minute.

2g of alcohol was added to the mixture and then 1g water was added. The mixture was shaken for more than 1 day.

To obtain the final product, the mixture was filtered and dried in vacuum.

Table 11

Sample No.		33	34	35	36	37	38	39	40	41	42
Clay (Cloisite Na) (gram)		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Polymer surfactant	PIBQS (gram)	1.00	1.00	0.70	0.40	0.10	0.00	0.00	0.00	0.00	0.00
	PIB <sub>2</sub> QS <sub>2</sub> (gram)	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.70	0.40	0.10
Low molecular weight surfactant	C18-2 (gram)	0.00	0.63	0.44	0.25	0.06	0.00	0.630	0.44	0.25	0.06

Sample No.		43	44	45	46	47	48	49	50
Clay (Cloisite Na)		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Polymer surfactant	PIBQS (gram)	1.00	1.00	0.70	0.40	0.10	0.00	0.00	0.00
	PIB <sub>2</sub> QS <sub>2</sub> (gram)	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.70
Low molecular weight surfactant	C18-2 (gram)	0.00	0.63	0.44	0.25	0.06	0.00	0.630	0.44

C18-2; dimethyldioctadecylammonium bromide

[00074] Thermo-gravity analysis (TGA) showed that the clay contained 41% of the organo-clay. Checked by low molecular weight angle x-ray, the clay was completely exfoliated (see Figs. 4-7).

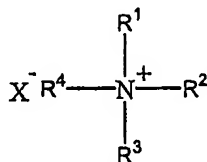
[00075] The butyl rubber compositions of the present invention can be formulated into any component or article for which butyl rubber is typically utilized. Typical articles for which the butyl rubber compositions can be used include, but are not limited to, inner-tubes and tire inner liners, air cushions, pneumatic sprays,

air bags, tire-curing bladders, high temperature hoses and conveyor belts, damping mounts for engines and the like.

[00076]           The invention has been described with reference to the exemplary embodiments. Modifications and alterations may appear to others upon reading and understanding the specification. The invention is intended to include such modifications and alterations insofar as they come within the scope of the claims.

Having thus described in the invention, we hereby claim:

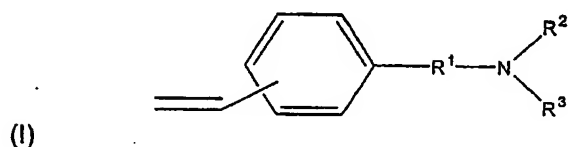
1. A butyl rubber composition of low gas permeability comprising:
  - a) an organically-modified clay,
  - b) butyl rubber, and
  - c) a polymeric exfoliant.
2. The composition of claim 1 wherein the butyl rubber composition includes between about 10 and 90 wt.% of an organically-modified clay that is capable of being exfoliated.
3. The composition of claim 1 wherein said organically-modified clay is derived from the combination of a low molecular weight surfactant with a clay selected from the group consisting of smectite, pyrophyllite, illites, glauconites, vermiculites, polygorskines, sepiolites, allophanes, imogolites, montmorillonite, synthetic mica and mixtures thereof.
4. The composition of claim 3 wherein said low molecular weight surfactant is selected from the group of organic salts having the general formula:



wherein X is a halide and R<sup>1</sup>, R<sup>2</sup>, R<sup>3</sup>, and R<sup>4</sup> are selected from H and C<sub>1</sub>-C<sub>20</sub> alkyl chains, which may be linear or branched, further wherein the alkyl chain may optionally contain an aromatic moiety and wherein at least one of the R<sup>1</sup>-R<sup>4</sup> is a C<sub>4</sub>-

C<sub>30</sub> alkyl chain, which may be linear or branched any may optionally contain a aromatic moiety.

5. The composition of claim 1 wherein said polymeric exfoliant is selected from the group consisting of PIBQS, PIB<sub>2</sub>QS<sub>2</sub>, PIBAS, a modified butyl rubber and a randomly NR<sub>2</sub>-functionalized poly(isobutylene) which is prepared by co-polymerizing isobutylene with a compound having the formula:



where R<sup>1</sup> is a bond or is an alkylene group selected from C<sub>1</sub>-C<sub>18</sub> linear or branched alkylene, C<sub>3</sub>-C<sub>20</sub> cycloalkylene and C<sub>6</sub>-C<sub>24</sub> arylene groups, further wherein R<sup>1</sup> may contain ether or tertiary amine groups and R<sup>2</sup> and R<sup>3</sup> are independently selected from C<sub>1</sub>-C<sub>18</sub> linear or branched alkyl, C<sub>3</sub>-C<sub>20</sub> cycloalkyl and C<sub>6</sub>-C<sub>24</sub> aromatic, further wherein the R<sup>2</sup> and R<sup>3</sup> groups may contain ether or tertiary amine groups.

6. The composition of claim 5 wherein the polymeric exfoliant is a compound prepared by co-polymerizing Isobutylene with a compound of formula I wherein R<sup>1</sup> is methylene and R<sup>2</sup> and R<sup>3</sup> are methyl.

7. The composition of claim 5 wherein said polymeric exfoliant is PIBQS, PIB<sub>2</sub>QS<sub>2</sub>, or PIBAS.

8. The composition of claim 3 wherein said low molecular weight surfactant comprises an organic ammonium salt.

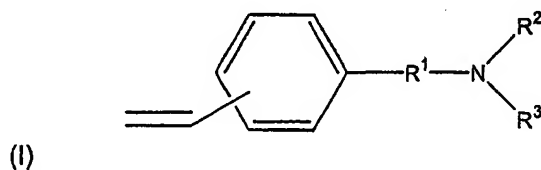
9. A method for lowering the gas permeability of a butyl rubber composition comprising dispersing an exfoliated clay in a butyl rubber compound wherein said exfoliated clay is derived from the reaction of an organically-modified clay and a polymeric exfoliant.

10. The method of claim 9 wherein said organically modified clay is obtained by combining a clay and organic surfactant having a molecular weight below about 500 ~2000.

11. The method of claim 9 wherein said butyl rubber composition comprises between about 10 and 90 wt.% exfoliated clay.

12. The method of claim 9 wherein said butyl rubber comprises one of bromo-butyl rubber, chloro-butyl rubber, butyl extended rubber, or mixtures thereof.

13. The method of claim 9 wherein said polymeric exfoliant is selected from the group consisting of PIBQS, PIB<sub>2</sub>QS<sub>2</sub>, PIBAS, and a randomly NR<sub>2</sub>-functionalized poly(isobutylene) which is prepared by co-polymerizing isobutylene with a compound according to the formula:



where R<sup>1</sup> is a bond or is an alkylene group selected from C<sub>1</sub>-C<sub>18</sub> linear or branched alkylene, C<sub>3</sub>-C<sub>20</sub> cycloalkylene and C<sub>6</sub>-C<sub>24</sub> arylene groups, further wherein R<sup>1</sup> may contain ether or tertiary amine groups and R<sup>2</sup> and R<sup>3</sup> are independently selected

from C<sub>1</sub>-C<sub>18</sub> linear or branched alkyl, C<sub>3</sub>-C<sub>20</sub> cycloalkyl and C<sub>6</sub>-C<sub>24</sub> aromatic, further wherein the R<sup>2</sup> and R<sup>3</sup> groups may contain ether or tertiary amine groups.

14. The method of claim 13 wherein the polymeric exfoliant is a compound prepared by co-polymerizing isobutylene with a compound of formula I where R<sup>1</sup> is methylene and R<sup>2</sup> and R<sup>3</sup> are methyl.

15. A dry mixing process for providing a butyl rubber composition having low gas permeability comprising:

- a) modifying a clay using at least one organic surfactant having a molecular weight below about 500 ~ 2000 to produce an organically modified clay;
- b) exfoliating the organically-modified clay with a polymeric exfoliant by admixing the polymeric exfoliant with the organically modified clay to produce an exfoliated clay; and
- c) dry mixing the exfoliated clay with butyl rubber.

16. The process of claim 15 wherein the dry mixing is done by using a mixer selected from a Brabender mixer, a twinscrew extruder and a kneader at a speed of from about 1 to about 500rpm.

17. The process of claim 15 wherein the dry mixing takes place at a temperature of from about 25°C to about 300°C.

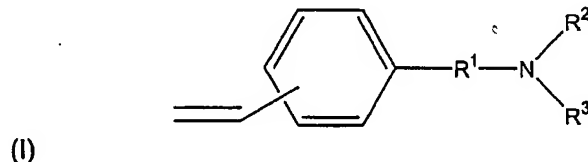
18. The process of claim 15 wherein the mixing is done at a speed of about 60rpm at a temperature of about 70°C.



19. The process of claim 15 wherein the dry mixing is done in the substantial absence of solvent.

20. The process of claim 15 wherein the butyl rubber composition comprises between about 10% and 90% by weight exfoliated organically-modified clay.

21. The process of claim 15 wherein said polymeric exfoliant is selected from the group consisting of PIBQS, PIB<sub>2</sub>QS<sub>2</sub>, PIBAS, and a randomly NR<sub>2</sub>-functionalized poly(isobutylene) which is prepared by co-polymerizing isobutylene with a compound according to the formula:

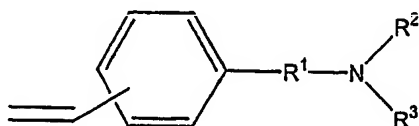


where R<sup>1</sup> is a bond or is an alkylene group selected from C<sub>1</sub>-C<sub>18</sub> linear or branched alkylene, C<sub>3</sub>-C<sub>20</sub> cycloalkylene and C<sub>6</sub>-C<sub>24</sub> arylene groups, further wherein R<sup>1</sup> may contain ether or tertiary amine groups and R<sup>2</sup> and R<sup>3</sup> are independently selected from C<sub>1</sub>-C<sub>18</sub> linear or branched alkyl, C<sub>3</sub>-C<sub>20</sub> cycloalkyl and C<sub>6</sub>-C<sub>24</sub> aromatic, further wherein the R<sup>2</sup> and R<sup>3</sup> groups may contain ether or tertiary amine groups.

22. The process of claim 21 wherein the polymeric exfoliant is prepared by co-polymerizing isobutylene with a compound of formula I wherein R<sup>1</sup> is methylene and R<sup>2</sup> and R<sup>3</sup> are methyl.

23. The process of claim 21 wherein said polymeric surfactant is PIBQS, PIB<sub>2</sub>QS<sub>2</sub>, or PIBAS.

24. A polymeric exfoliant which is a randomly NR<sub>2</sub>-functionalized poly(isobutylene) which is prepared by co-polymerizing isobutylene with a compound according to the formula:



(I)

where R<sup>1</sup> is a bond or is an alkylene group selected from C<sub>1</sub>-C<sub>18</sub> linear or branched alkylene, C<sub>3</sub>-C<sub>20</sub> cycloalkylene and C<sub>6</sub>-C<sub>24</sub> aromatic groups, further wherein R<sup>1</sup> may contain ether or tertiary amine groups and R<sup>2</sup> and R<sup>3</sup> are independently selected from C<sub>1</sub>-C<sub>18</sub> linear or branched alkyl, C<sub>3</sub>-C<sub>20</sub> cycloalkyl and C<sub>6</sub>-C<sub>24</sub> aromatic, further wherein the R<sup>2</sup> and R<sup>3</sup> groups may contain ether or tertiary amine groups.

25. The polymeric exfoliant of claim 24 which is a compound prepared by reacting isobutylene with a compound of formula I wherein R<sup>1</sup> is methylene and R<sup>2</sup> and R<sup>3</sup> are methyl.

26. A polymeric exfoliant which is polyisobutylene quaternary ammonium salt (PIBQS), PIB<sub>2</sub>QS<sub>2</sub> or polyisobutylene amine salt (PIBAS).

27. A process for providing a butyl rubber composition having low gas permeability comprising:

- a) dissolving a polymeric exfoliant in a solvent for the polymeric exfoliant;

- b) swelling clay in a mixture of clay and water;
- c) combining the products of steps a) and b);
- d) drying the product of step c) to obtain an organo-clay;
- e) mixing the product of step d) with butyl rubber at about 70°C to about 175°C

wherein the butyl rubber produced by the process has the organo-clay incorporated therein thereby imparting low gas permeability properties to the butyl rubber.

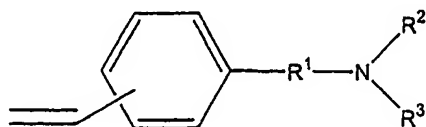
28. The process of claim 27 wherein the polymeric exfoliant is PIBQS, PIB<sub>2</sub>QS<sub>2</sub>, or PIBAS.

29. The process of claim 28 wherein the PIBQS, PIB<sub>2</sub>QS<sub>2</sub>, is mixed with a solvent.

30. The process of claim 29 wherein the solvent is selected from the group consisting of THF, diethyl ether, and MEK.

31. The process of claim 28 wherein the mixture of step e) is mixed at about 30 to about 120 rpm for about two to about ten minutes.

32. A process for producing a randomly NR<sub>2</sub>-functionalized poly(isobutylene) by copolymerizing isobutylene with a compound having the formula:



(I)

where  $R^1$  is a bond or is an alkylene group selected from  $C_1$ - $C_{18}$  linear or branched alkylene,  $C_3$ - $C_{20}$  cycloalkylene and  $C_6$ - $C_{24}$  arylene groups, further wherein  $R^1$  may contain ether or tertiary amine groups and  $R^2$  and  $R^3$  are independently selected from  $C_1$ - $C_{18}$  linear or branched alkyl,  $C_3$ - $C_{20}$  cycloalkyl and  $C_6$ - $C_{24}$  aromatic, further wherein the  $R^2$  and  $R^3$  groups may contain ether or tertiary amine groups in a solvent system in the presence of  $TiCl_4$ .

33. The process of claim 32 wherein  $R^1$  is an alkylene group.
34. The process of claim 33 wherein  $R_2$  and  $R_3$  are methyl.
35. The process of claim 34 where  $R^1$  is a methylene group.
36. The process of claim 32 wherein the solvent system comprises a chlorinated solvent.
37. The process of claim 36 wherein the solvent system is admixed with the isobutylene prior to reacting said isobutylene with the compound of formula I.
38. The process of claim 37 wherein the solvent system comprises hexane and methyl chloride.
39. The process of claim 32 wherein a modifier is admixed with the compound of formula I prior to reacting the compound of formula I with the isobutylene.
40. The process of claim 39 wherein an initiator compound is further included with the compound of formula (I) prior to admixing with the isobutylene.

41. The process of claim 40 wherein the initiator is  $\alpha$ ,  $\alpha$ ,  $\alpha'$ ,  $\alpha'$ -tetramethyl-1,4-benzene-dichloride.

42. The process according to claim 37 wherein after admixing the first solvent system with the isobutylene, the resulting mixture is cooled to below about 0°C.

43. The process according to claim 37 wherein the mixture of the first solvent system and isobutylene is cooled to at least about -78°C.

44. A process for synthesizing a randomly NR<sub>2</sub>-functionalized poly(isobutylene) by cationic polymerization comprising the steps of:

- a) mixing isobutylene in a solvent system;
- b) cooling the isobutylene/solvent mixture;
- c) adding N,N-dimethylvinylbenzylamine to the mixture as initiator and modifiers;
- d) initiating a polymerization reaction by adding TiCl<sub>4</sub>;
- e) terminating the polymerization with MeOH; and
- f) evaporating any remaining solvents;

wherein the resulting product of poly(isobutylene-co-N,N-dimethylvinylbenzylamine) is yielded.

45. The process of claim 44 wherein the solvent system comprises hexane and methyl chloride.

46. The process of claim 44 wherein the modifiers comprise dimethylacetamide and di-t-butylpyridine.

47. The process of claim 44 wherein the initiator is  $\alpha, \alpha, \alpha', \alpha'$ -tetramethyl-1,4-benzene-dichloride.

48. The process according to claim 44 wherein after admixing the first solvent system with the isobutylene, the resulting mixture is cooled to below about 0°C.

49. The process according to claim 44 wherein the mixture of the first solvent system and isobutylene is cooled to at least about -78°C.

50. A product produced by the process of claim 32.

51. A product produced by the process of claim 44.

52. A process for producing polyisobutylene amine salt (PIBAS) comprising the steps of:

a) mixing polyisobutylene succinic anhydride (PIBSA) with a multi- amine compound selected from, for example, 3-(dimethylamino)propylamine, tetraethylene pentamine, 3,3'-diamino-N-methyl dipropylamine, 1-(2-aminoethyl)piperazine, 4-amino-1-benzylpiperidine, dimethylaminovinylbenzylamine, polyethyleneimine, 3-aminopyrrolidine, 3-(dimethylamino)pyrrolidine and N,N'-Bis(3-aminopropyl)ethylene diamine;

b) heating the mixture to about 150°C;

c) maintaining the heated mixture at about 150°C for about five minutes;

d) allowing the mixture to cool;

e) adding HCl and water to the cooled mixture of step d);

wherein PIBAS is thereby formed.

53. A process for producing polyisobutylene quaternary salt (PIBQS) comprising steps a) through c) of claim 52, then

d) adding an alkylating agent; and

e) heating to form PIBQS.

54. The process of claim 53 wherein the alkylating agent is selected from methyl chloride, benzyl chloride, dimethyl sulfate, diethylsulfate, and  $\alpha,\alpha'$ -dibromoxylene.

55. A method for exfoliating clay comprising

a) combining said clay with an organic exfoliant having a molecular weight less than about 700;

b) combining a polymeric surfactant having a molecular weight greater than about 1,000 with an organic solvent;

c) combining the mixtures of steps a and b and introducing water thereto; and

d) drying the mixture of step c and recovering said exfoliated clay.

56. The method of claim 55 wherein said organic surfactant comprising an organic salt.

57. The method of claim 56 wherein said organic salt is dioctadecyldimethyl ammonium salt.



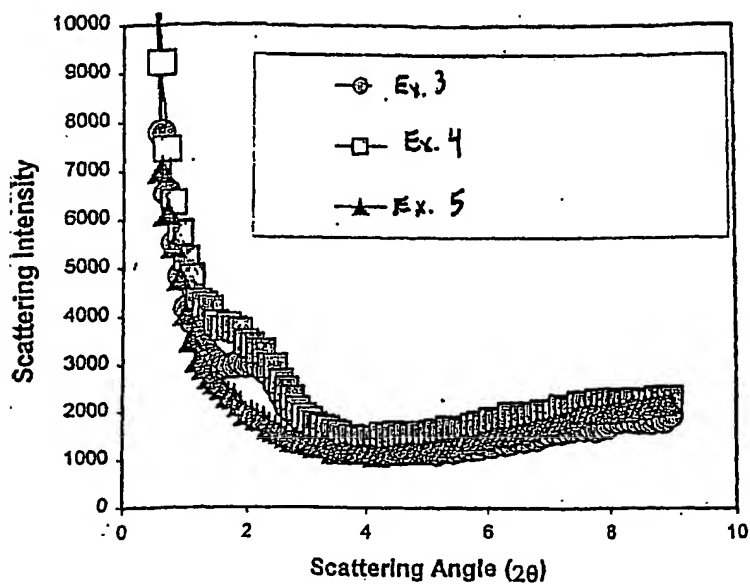


Figure 1

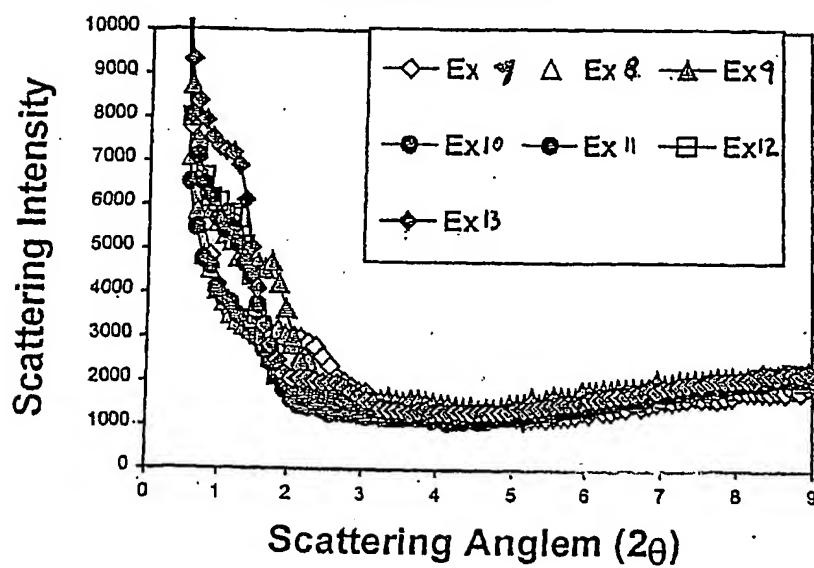


Figure 2

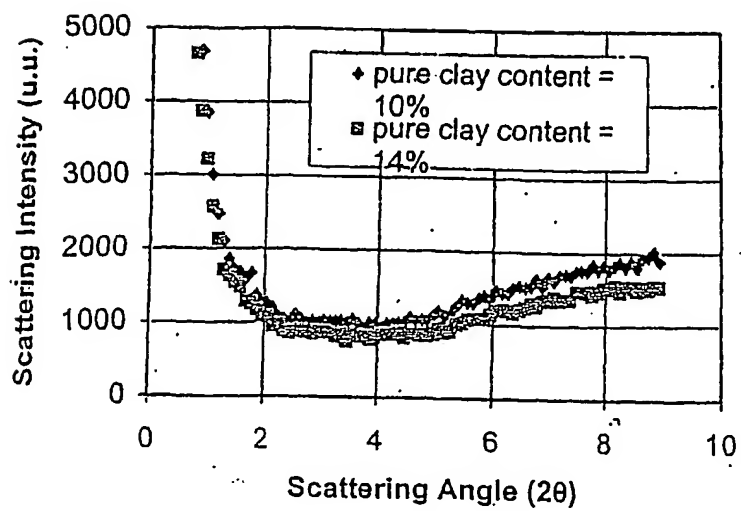


Figure 3

Figure 4

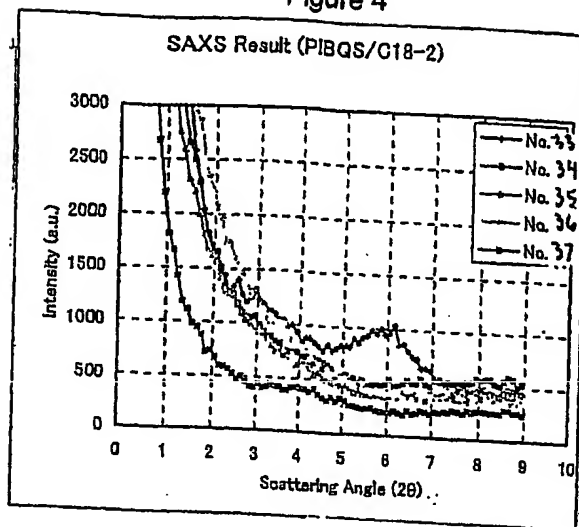


Figure 5

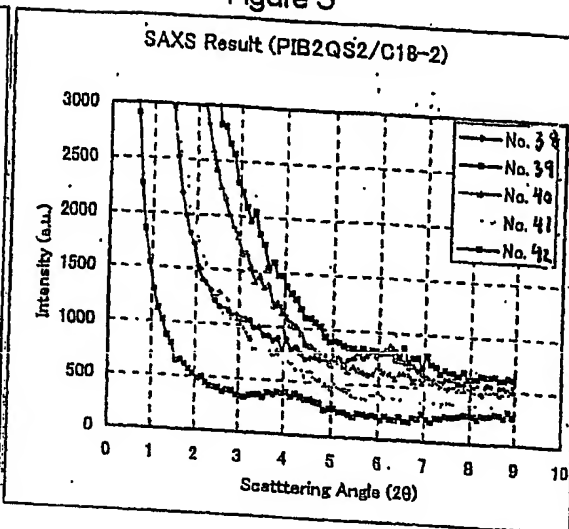


Figure 6

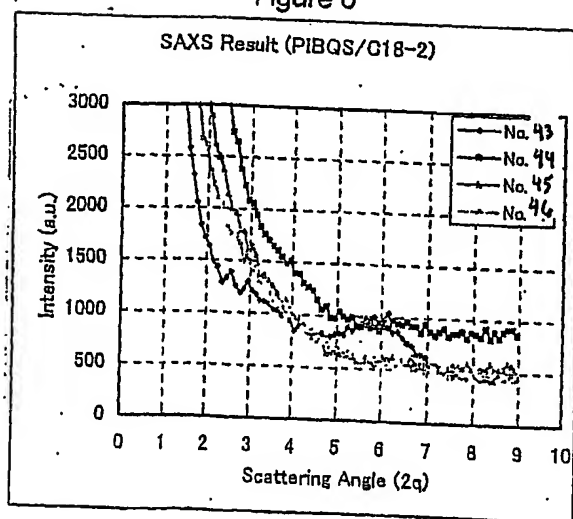
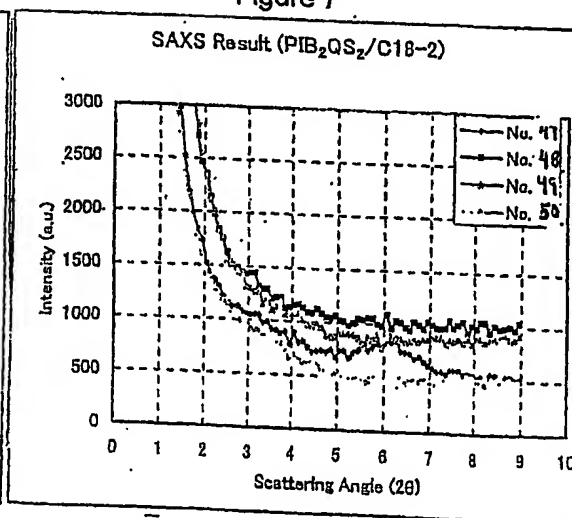


Figure 7



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